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F. Stauffert

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16. Abstract
This article discusses the arrangement, sizes, and kinds of airport beacons necessary if aircraft landings are to be made in conditions of poor visibility. The amount of candlepower needed for a given visibility range is derived. Installation of the beacons, in terms of arrangement with respect to lane markers and angle with the horizontal, and also with respect to the kind of construction used for the runway, is discussed.

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MODERN BEACONING IN AIRPORTS FOR BAD-WEATHER FLIGHTS†† /51*

F. Stauffert†

Editor's Note. This article was written before the technical meeting of the ICAO held in Montreal at the end of October, 1964. Although modifications were introduced in the arrangement of the beaconing lines and calculation of light intensity, it seemed useful to publish Mr. Stauffert's article, which will be supplemented in a later issue by a technical note summarizing the new provisions adopted by the Organization.

In present-day civil aviation, landings can be made with minimum visibility of 800 m and a ceiling of 60 m. To achieve greater air traffic regularity, even in bad weather, it will be necessary in the future to permit landings with a 400 meter visibility and a ceiling of 30 m, as defined by the aims of the ICAO (International Civil Aviation Organization). In this way we would progressively dispense with a semi-automatic landing, even with ground-level cloud.

Under these conditions, reduction of atmospheric minimums is only possible by considerably tightening the tolerances of the instrument landing system (ILS). The first experimental systems are already in service and are giving good results. In addition, it is essential to adapt light-beacon systems to these new conditions.

Practical experience teaches us that the oblique distance between the aircraft and the most distant light which must be recognized, has to be a minimum of 450 meters so that any necessary piloting corrections may be made safely. Allowing for the high landing speed of modern aircraft, we have to reckon with a distance of approximately 600 m.

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†† Translated from German by L. Boge, Engineer.

* Numbers in the margin indicate pagination in the foreign text.

Taking the case that visibility on board the aircraft is not limited by cloud, but is influenced only by virtually homogeneous atmospheric haze, the intensity of the navigation light essential for recognizing light beacons at given distances is calculated by Allard's equation:

$$J = \frac{Er^2}{q^r}$$

in which

J = intensity of light

E = threshold of illumination perceived by the eye of the observer

q = transparency of atmosphere

r = distance of observation.

Figure 1 shows the relationship between the distance of observation 4 and the intensity J of the lights. These curves were plotted for daylight observation with visibility 800 m or 400 m. Under these conditions, the threshold value E adopted for the illumination is 10^3 lux, which ensures identification of the light. /52
The continuous-line curves apply to observation from the aircraft,

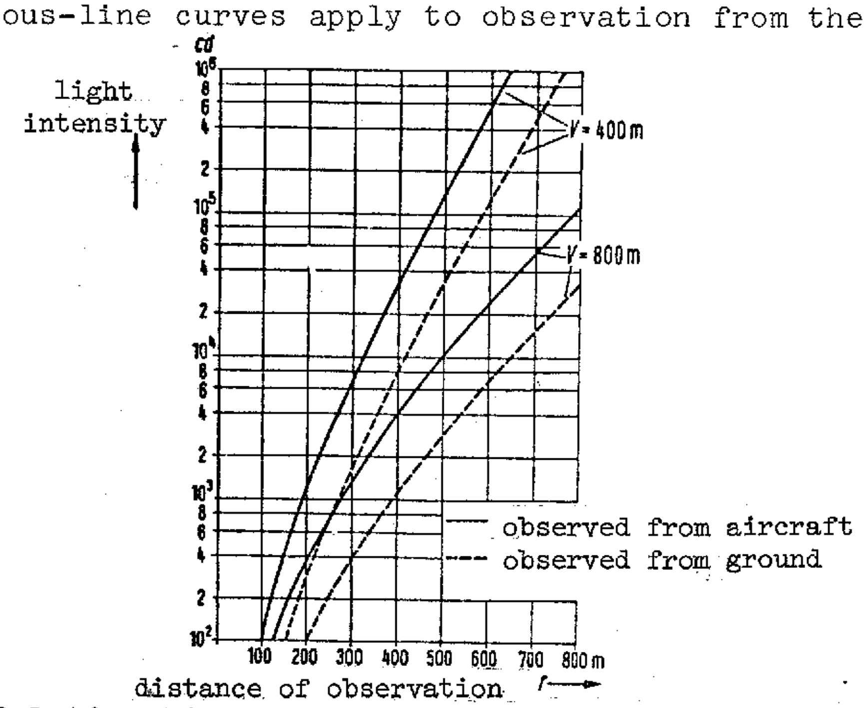

Figure 1. Relationship between intensity T and distance of observation r for daytime observation of lights with visibilities of 400 and 800 meters.

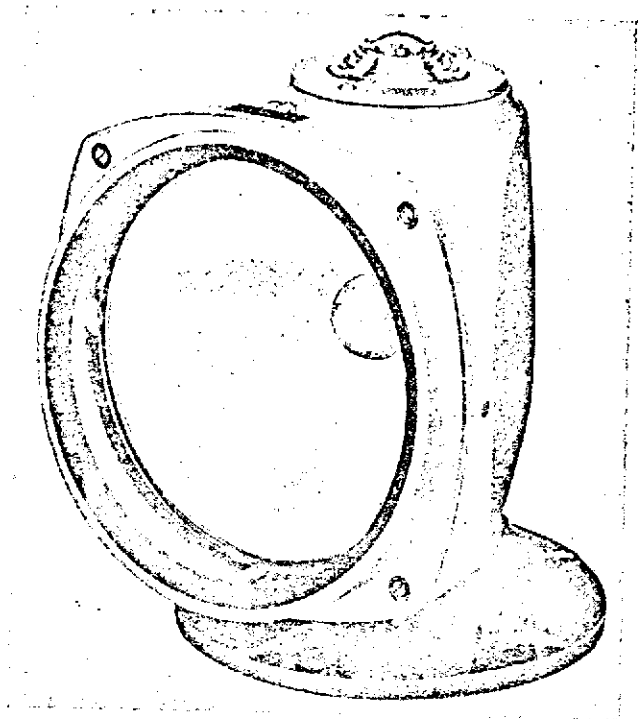

Figure 2. Lane-distance pencil-beam naviation light. It can also be fitted with 200 W, 6.6 A quartz-iodine lamps. If a scattering glass plate is used, maximum intensity is 85,000 candlepower. With a plane plate, the candlepower reaches 350,000.

and the dashed curves to meteorological observation from the ground. The visibility distance is deduced from the values read on the ground.

As a consequence, a light with an intensity of about 20,000 candlepower will be recognized from an approximate distance of 600 m for 800 m visibility. If we wish the device to be visible under the same atmospheric conditions at a distance of only 450 m, about 6500 candlepower is sufficient. On the other hand, for future landings with visibilities of only 450 m, 7×10^4 candlepower is essential. Modern navigation lights, such as that shown in Figure 2, reach this intensity. These lights were recently equipped with iodine-quartz lamps with a rated service life of 1000 hours, while that of the projector lamps hitherto used was only 100-300 hours. In optical technology they are equivalent. Since the bulb does not blacken with use, and hence the intensity remains almost constant, the operational safety of such apparatuses for airport light-beaconing is considerably increased.

Intensities of about 5.5×10^5 are essential for distances of observation of 600 m with 400 m visibility. In general, navigation lights equipped with 200 W lamps have not thus far reached these high intensities. To adapt them as best as is possible to the required value, it is necessary either to increase the luminous intensity, or to reduce light scattering. In general, technical difficulties and a sharp rise in costs militate against increasing the power of the lamps, so, for the time being at least, efforts are being made in the direction of the second solution: reducing light scattering. This seems to be valid, since the tolerance with which airplanes will in the future be brought to the landing strip by instrument flying will be considerably heightened, and the space inside of which the light beacon must be recognized will be cut down.

On the other hand, if flights are performed under contract flying regulations (VFR flights) high-intensity light beaconing is not essential. It is possible, under these flying conditions, to be content with light intensities on the order of those beamed /53 in all directions from low-power systems. The navigation lights are, for this purpose, equipped with beam concentrators and relatively weak lamps.

With lower cloud limits at an altitude of 30 m, which is the lower boundary of the new atmospheric minimum, we are dealing not only with compact clouds with fairly sharp edges but with blurred-edge fog patches. In these cases, after passing through the meterologically determined ceiling, which, practically speaking, represents vertical visibility, the light beacon is not instantly, but gradually, perceptible. Reinforcement of lighting along the center lines, at least in the 300 meters before the threshold, will make it possible to identify the beacon sooner. For this reason, it seems appropriate to install, instead of the individual lights of the Calvert system, groups of five light transmitters packed closely together. These lights will be displaced horizontally with respect to one another by a few degrees so that the group provides the necessary propagation. Moreover a reciprocal influence arises between these close-packed lights with the result that the group can be perceived from a greater distance than would be a single light of the same power.

In similar cases, the flashing navigation lights mounted in the axis of the center line of the beaconing system provide the pilot with an essential aid. These flashing lights are connected so that the one farthest from the landing strip switches on first, and the others follow in series. This procedure is repeated twice per second, and it looks to the pilot as if shining balls were rolling towards the runway at high speed.

Although these flashing lights radiate at an intensity of about 8×10^6 candlepower, the distance from which they are recognizable in poor weather is not very much greater than that at which a good beacon with incandescent lamps is visible. This can partially be explained by the shortness of the flash: about 0.4 ms. As the inertia of the human eye does not permit it to follow a rapid increase in luminous excitation, the eye perceives only part of the light intensity radiated. However, flashing beacons have assumed considerable importance, which they will retain in the future since this method of beaconing due to the effect of movement, marks without error the route towards the landing strip. The pilot is thus more quickly able to think out and perform the necessary course corrections.

The flashes have thus far been triggered by relays. Due to the high switching frequency and the high electric charge of the contacts, these relays are subject to wear and tear and must be changed

rather frequently. To avoid this drawback, "contact-less" lights are now for the first time being controlled by thyristors (thyratron-silicium). This semi-conductor element has an almost limitless service life, leading to a considerable increase in operating security of flashing lights. Figure 3 represents one of these devices. It is possible to mount the circuit required to operate the flash lamps outside the device such that connection cables can be as long as 25 meters. The light itself, in which only the flash trigger is built in, weighs only 20 kg. which is advantageous and inexpensive for mounting on masts. When, in the future, the pilot has to land under conditions such that he distinguishes lights only at an altitude of 30 meters, he must, each time, according to his approach angle, fly over a fairly large region of the 900 m of light beacons until he sees them. The remaining visible part, i.e. 260 m for a 2° approach angle, or only 170 m for a 3.5° angle, is too short for him to be able to make any necessary course corrections. It then becomes necessary, in addition to the usual /54
beaconing of runway edges, to build into the runway an effective beaconing system to supplement the navigation beacons.

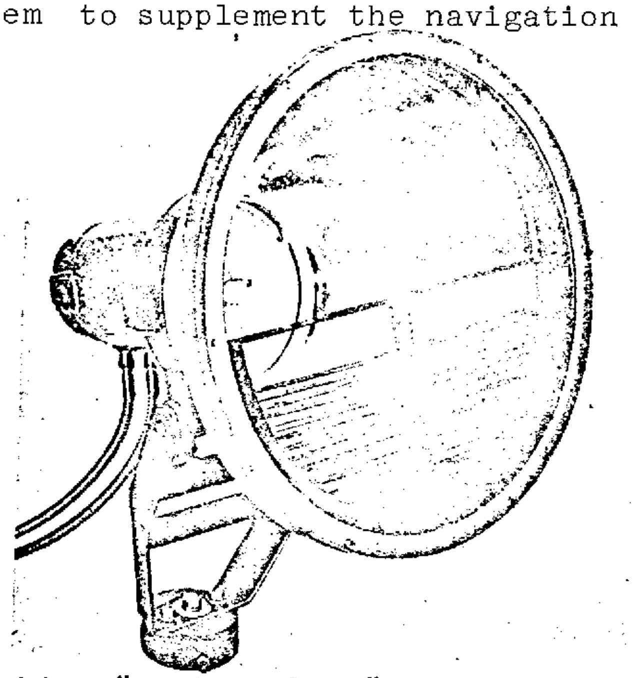

Figure 3. Flashing "contact-less" navigation light, triggered electrically.

This problem can be solved by the narrow-gauge system recently developed. The original purpose of this lighting was only to illuminate the "black hole" occuring when the pilot, after flying over the beginning of the landing or takeoff strip, no longer sees the lights arranged along the center line, but only the side beacon lights. Moreover, due to this light system, each part of the landing strip where the machine is to touch down can be identified without error.

The narrow-gauge system is composed of lights built flush with the runway over which the aircraft's wheels can pass. They are built into the first 900 meters of the landing strip and each consist of groups of three flush-mounted lights at about 10 meters on both sides of the runway center line, to which they are perpendicular. The intensity of these built-in lights must, as much as is possible, be matched with that of the navigation lights and the light propagation can be less than that of the other lights. The difficulty at present resides in the radiation of high-intensity light at an elevation angle of only 2° to 5° with respect to the plane of the runway, which is why the lights must as much as possible be built flush with the ground so as not to be an obstacle to a moving aircraft nor make it difficult to clear snow from the runway.

In principle, there are today three types of built-in lights, working differently from the optical point of view. On the first type (see Figure 4) which underwent testing in Germany, the optical elements and the lamps are in the central part. These lights have recently been equipped with iodine-quartz lamps. Two lamps mounted near each other are installed vertically in parabolic mirrors. A plane mirror placed above deflects the light in the desired direction.

Since the intensity of the light is proportional to the luminance of the lamp and to the visible surface of the mirror, the light exit aperture, through which the mirror is visible, must be

made as large as possible. Moreover, it is necessary to beam as /55
much light power as possible at an angle of only 3° with respect to the plane of the runway. Hence, in front of the light aperture, walls must be placed between which the light can radiate in the desired directions. The walls of the "light conduits" permit the built-in light to be mounted flush with the ground, and the device is not an obstacle for a moving plane. The conduits are equipped with heaters to prevent ice or snow from being deposited.

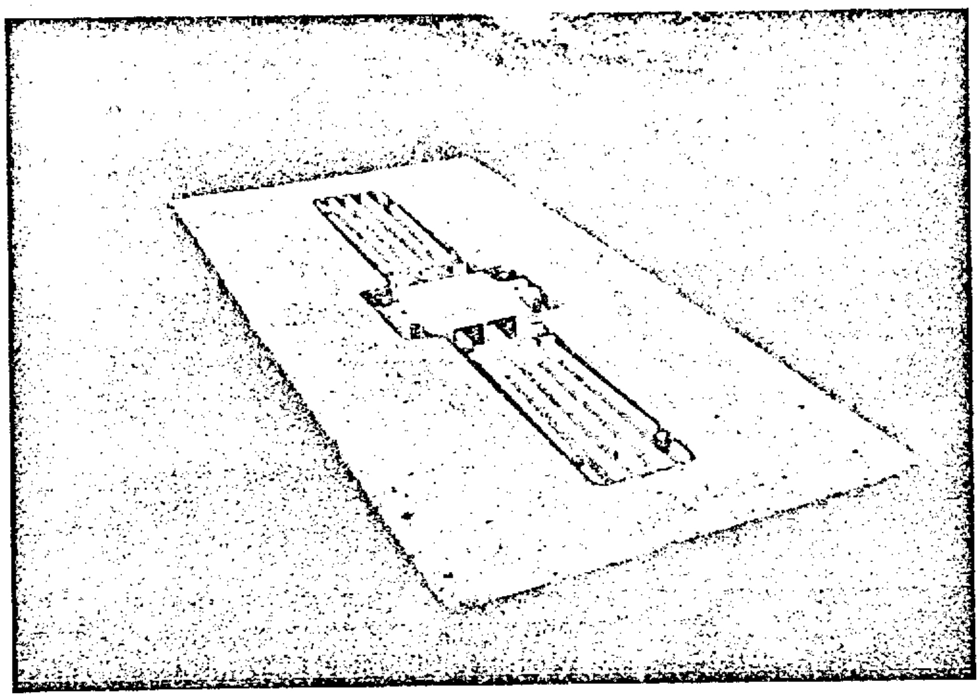

Figure 4. Light flush-mounted on runway, with "light conduits". It is equipped with two 100 W 6.6 A iodine-quartz lamps in each direction of radiation. The conduits can be heated, and the maximum candlepower is about 30,000.

Installation of these lights in conventionally-built runways is relatively simple and needs no explanation. On the other hand, with reinforced-concrete runways, it is necessary to construct, under the cavity, an independent runway foundation in which the central part of the light is installed. This foundation rests on a bed of sand. The light is supported on this foundation and remains continuously stable in the same position however the runway may be deformed. Figure 5 shows an example of these foundations for reinforced concrete runways. The conduits are so shallow that they can be let into the top layer of the runway with no difficulties or loss of strength from displacement of the metal reinforcements.

There are also other lights based on the same principle. They are composed of one or more powerful projectors mounted in separate cavities, projecting their light at a very low angle over the plane of the runway. The light conduits are also essential here, and the light escapes along their walls. The length of the conduit here depends on the dimensions of the projection, the depth of mounting below the runway surface, and the given angle of radiation. It goes without saying that flush-mounted lights of this type require relatively long conduits. Moreover they have very high intensity, /56
provided projectors with large enough mirrors are used.

It is also possible to construct a second type of built-in runway lights, using the refraction generated by a plane glass surface for an oblique light incidence, with the aim of deflecting it in the desired direction of radiation. Lights of this type are characterized by the fact that it is possible to build the closing glass plate fully flush with the runway surface, and no conduit is necessary to radiate the light. No extra heating is necessary in winter, since the closing glass, when the device is in service, reaches a high enough temperature to safely avoid snow and ice deposits. Figure 6 shows a built-in light of this type. The lamps are arranged in special covers, below the device, and are thus easily accessible. The emit a light beam made parallel by lenses and directly perpendicular to the section of the closing glass, cut obliquely. On the upper face of the latter it is refracted by a

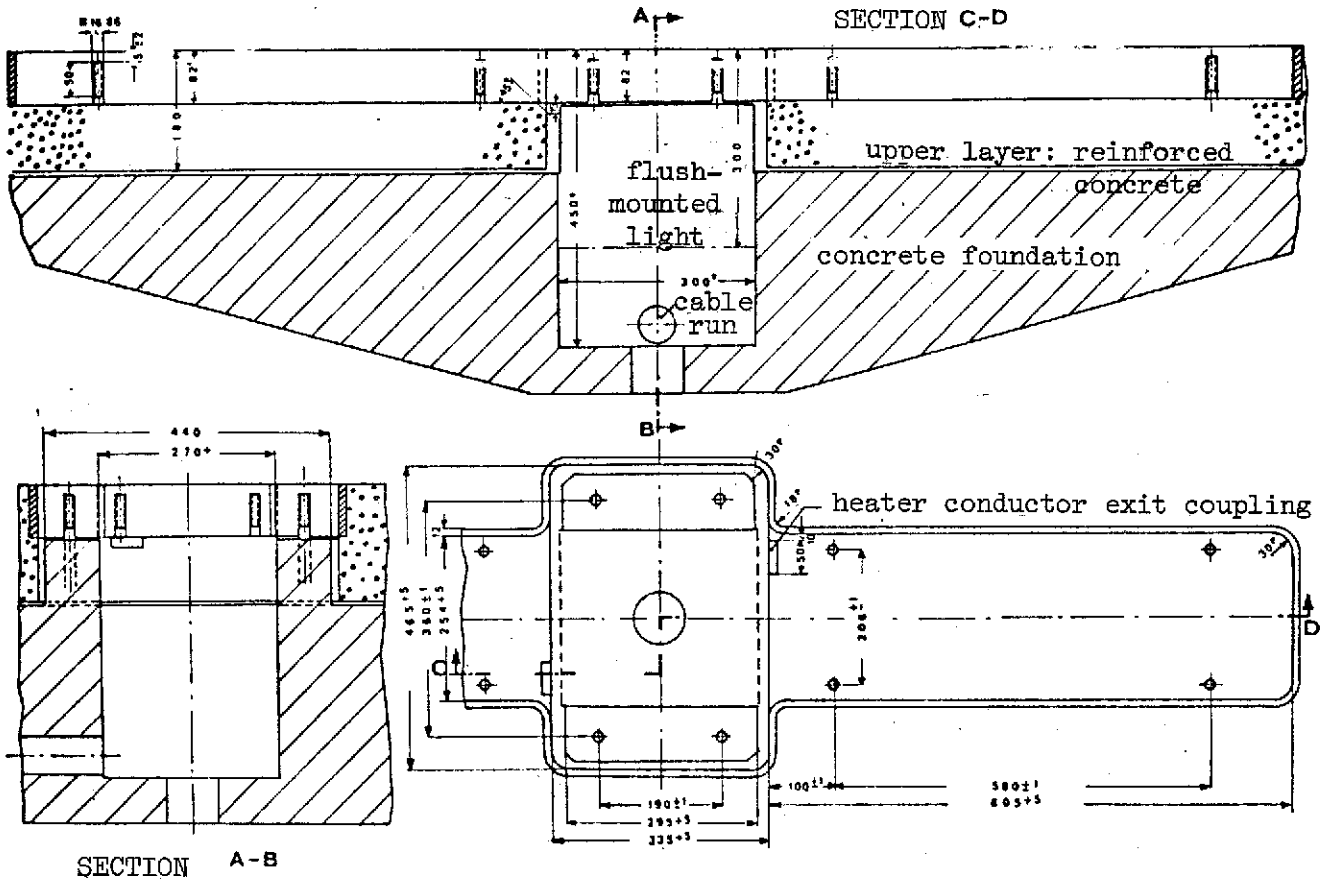

Figure 5. Example of building foundations for light mounted flush with the runway, with light conduits, for incorporation in a reinforced-concrete takeoff strip.

small angle with respect to the plane of the runway, this angle being a function of the angle of incidence, and beams the light in this direction.

In contrast to the lights described above, in which the light exit aperture is almost perpendicular to the direction of observation, the closing glass is mounted horizontally. Its apparent size is thus a function of the direction of observation. The smaller its angle and that of the plane of the runway, the shorter the distance of observation. As a result, also, the light intensity, /57 itself a function of the apparent lighting surface, decreases with a decreasing angle of observation. Moreover, the highest intensity is not radiated perpendicularly upward. This becomes comprehensible if we look at the optical conditions of refraction of light by the upper face of the glass. The relation between the direction of radiated light and the direction of light projected into the glass is given by the law of refraction:

$$n_b \sin \alpha = n_a \sin \beta$$

where:

α = angle of incidence

n_b = index of refraction of the material used for the glass

β = light exit angle

n_a = index of refraction of air

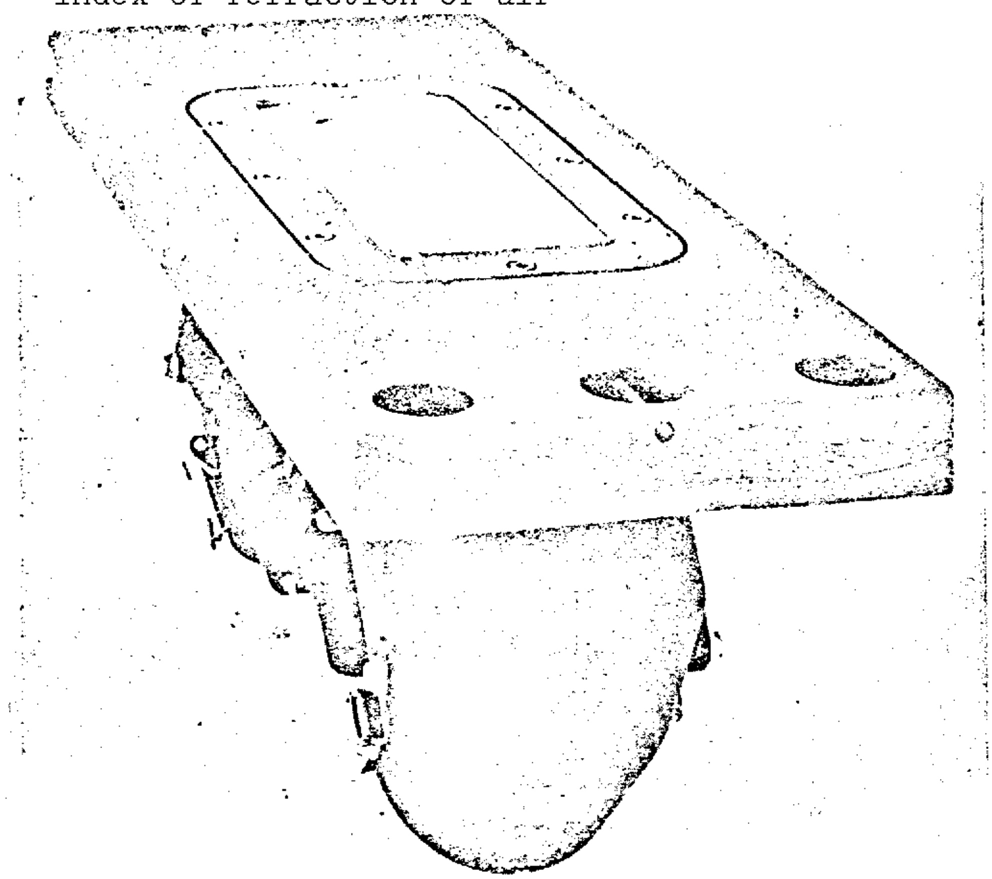

Figure 6. Runway light mounted flush with ground level, in which the closing glass plate is an integral part of the runway. The light is deflected on the outside face of the closing glass. Maximum candlepower about 24,000.

It can be seen from this equation that the total reflection comes from a given angle α for which $\beta \geqslant 90°$, and no light can leave the outer face of the glass. Curve 1 in Figure 7 shows the relation between the angle of incidence α and the angle of refraction β. For the material chosen in this example, total reflection occurs at α - 42.1°. For this angle of incidence, the relation between the light intensity reflected by the outside surface of the glass and the light intensity applied to the glass is unity. For other angles of incidence α and angles of refraction β connected with them, the reflected part J_R is calculated by the equation:

$$J_R = \frac{J_0}{2}\left(\frac{\sin(\alpha-\beta)}{\sin(\alpha+\beta)}\right)^2 + \left(\frac{tg(\alpha-\beta)}{tg(\alpha+\beta)}\right)^2$$

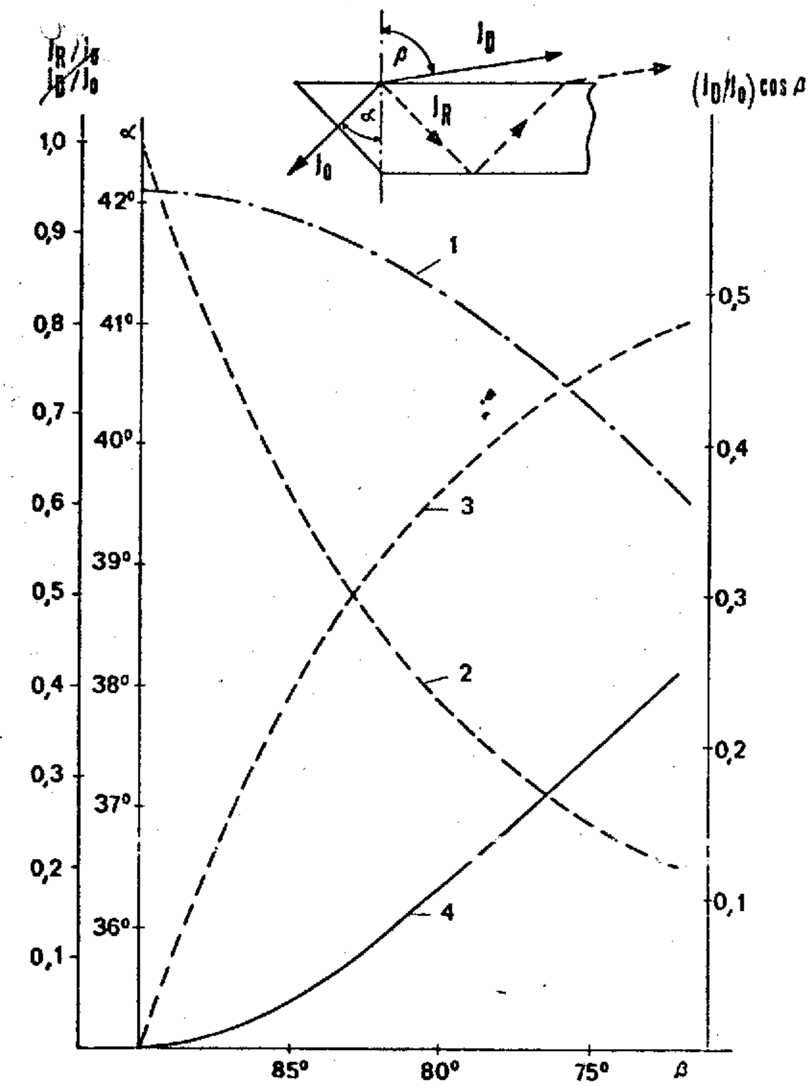

Figure 7.

Leaving out the parts in the glass, the part transmitted J_D is:

$$J_D = J_0 - J_R.$$

Curve 2 represents the relation between the ratio $J_R:J_0$ and the angle of refraction β.

Curve 3 represents the relation between the ratio $J_D:J_0$ and the angle of refraction β.

Curve 4 shows the shape of the function $(J_D/J_0) \cos \beta$, to which light intensity in the direction β is proportional.

We can see from these curves that, to improve performance it is necessary to utilize multiple reflection fully, which is done in the light represented by Figure 6. The light reflected by the upper face of the glass is sent by the lower glass-mirror at an angle α as many times as is necessary for the remaining losses not form a large part of the device's light intensity.

The angle of incidence α will be determined so that the light intensity of the device is as strong as possible in a 2° to 5° cone above the plane of the runway. The angle at which the maximum light intensity is strongest is a little larger.

Built-in lights of the third type are in some measure a compromise between the types described above. Their distinguishing feature is that they cannot be mounted entirely flush with the runway, but generally just out a few millimeters. The light exit surfaces are usually installed obliquely with respect to the runway to give the greatest possible surface at fairly modest cost. /58
In front of the light exit surfaces is a corridor by means of which the level difference with the runway is progressively equalized. In present constructions, the beam radiated by mirrors or sealed-beam lamps arranged horizontally is deflected in the desired direction through a prism placed behind the light exit aperture. After the introduction of iodine-quartz lamps, the lamp and a simpler mirror can be mounted behind the light exit aperture, such that the deflecting prism is no longer needed. On some models, the closing glass is comprised of a lens behind which the lamp is

located. In this way, it has become possible to produce a very inexpensive light which projects relatively high intensity at the small elevation angle desired 2°, to 5°. Figure 8 shows one of these devices, which can be sealed or screwed to the bottom of round cavities dug into the runway almost at ground level. Due to its small size, it is particularly applicable to installations subsequently made on existing runways. It should be noted that built-in lights of this type, now known as "pancakes," do not need special foundations, and for this reason present no watertightness problem. The cables can be buried later in conduits made in the runway. After the cables have been laid, the conduits are grounded.

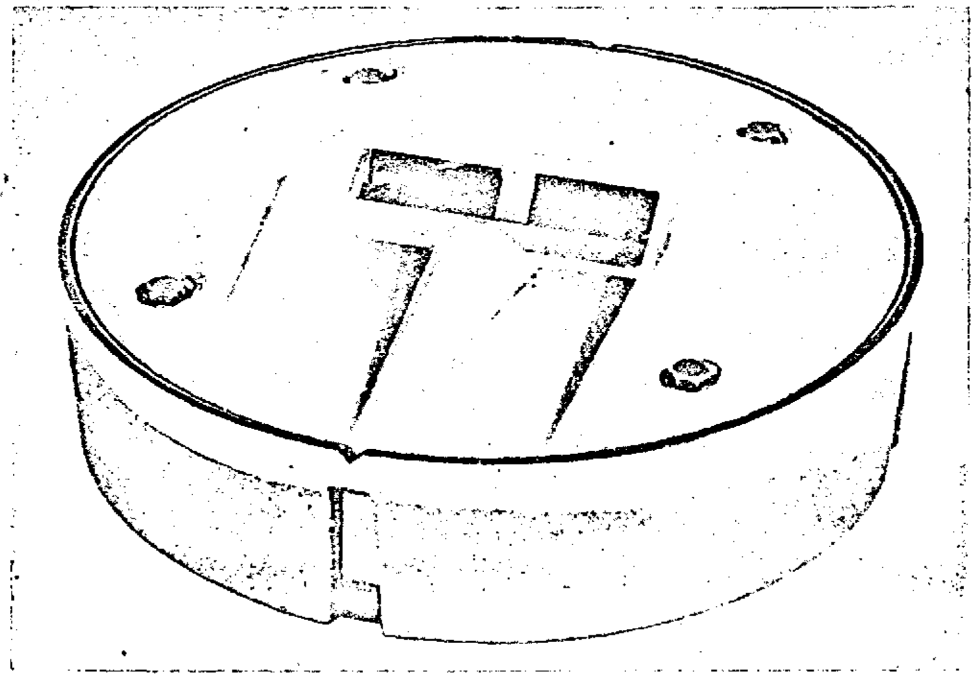

Figure 8. 200 W, 6.6 A iodine-quartz lamp "pancake" light flush-mounted on runway. Maximum candlepower: about 20,000.

The navigation and runway lights are not the only ones that have to be converted for future use: taxiway lights must also be modified. The lateral blue lights presently used become inadequate for ensuring sufficiently rapid and accident-free ground traffic. On fast taxiways, the prime consideration is that the center line be distinguished by built-in lights. In this case, the distance between each light should in no event be greater than 8 to 10 m for curves to be clearly indicated. The intensity of these devices needs to be high enough for three or four lights to be distinguished when taxiing under poor visibility conditions: this will be sufficient aid to the pilot.

The development of navigation aids shows that, in the future, the most important piloting problems will be resolved by the high-frequency technique. Nonetheless, light beaconing will be as important as before. If his instruments or devices break down, they are the pilot's only chance to bring his machine down safely on the landing strip.